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HF PROPAGATION ASSESSMENT STUDIES OVER PATHS IN THE ATLANTIC.(U)

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In September, 1980, NRL utilized Barry AN/TRQ-35 oblique sounding equipment which was deployed on board a ship operating in the Atlantic Ocean in order to test a concept to provide a real-time model update with the oblique sounder as a data source. The purpose of this work was to show that very accurate HF channel assessment was possible over paths in the local vicinity of the sounded path. Presented are initial results of an exercise encompassing two short paths (less than 900 km) in the North Atlantic.

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20. ABSTRACT *(Continued)*

These initial results indicate that by utilizing the oblique sounder to update the MINIMUF 3.5 model developed by NOSC, a significant increase in the accuracy of short term forecasting of the Maximum Usable Frequency (MUF) can be obtained. Over a 24-hr period, RMS errors from a model driven by the 5-day running average of 10.7 cm flux were approximately 4 MHz. Utilizing the oblique sounder as an update tool, this RMS error dropped to below 1 MHz. Further results are required, however, to validate the technique over longer periods of time, different geographies, and larger operational areas.

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HF PROPAGATION ASSESSMENT STUDIES OVER PATHS IN THE ATLANTIC

## 1.0 INTRODUCTION

Workers who are well acquainted with using the HF band (3-30 MHz) for communications know that in a low noise environment a reliable HF channel can be maintained at reasonable data rates provided the proper frequency, bandwidth, and antenna are selected. In fact, if these items are optimized it is reasonable to expect reliabilities approaching satellite links. Unfortunately, because of the nature of the beast, the information bandwidth is not as great as with satellite systems.

In the past, the tack has been taken to devise equipment and techniques to improve the system performance under poor channel conditions. Work devoted to this end include improved antenna design, increased transmitter power, modulation and detection techniques commensurate with the medium, diversity techniques, and error correction techniques. These methods generally offer some improvement, but the performance of the channel generally remains below that which is desired. A substantial improvement, however, can be gained by selecting the optimum channel between the transmitter and receiver. Oblique sounding and techniques relying on it play an important role in assisting in this optimization. The work presented herein suggests a novel use of the oblique sounder to provide an update to a model which determines the characteristics of the HF channel between two points. It is shown that, at least in the initial work, significant improvement in the RMS error between actual channel data and the model occurs employing this model update scheme.

## 2.0 BACKGROUND

### 2.1 General

NRL initiated an examination of the potential for updating various ionospheric propagation model calculations for Navy uses when presented with the possibility that the Air Force was planning to launch an advanced technology topside ionospheric sounder as part of its environmental assessment program to support communication and surveillance requirements. In order to determine the success of each model update procedure and specifically the procedure which would exploit topside sounder data, it was necessary to assess the HF channel more directly in order to have a basis for comparison. In the process of designing experiments to acquire the type of data needed to test the update hypothesis, NRL attempted to take advantage of various scheduled operations which employed oblique sounders to do HF channel assessment. The equipment currently being utilized in

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these operations is the Barry AN/TRQ-35 Tactical Frequency Management System (TFMS). It is from data extracted from this system that a direct assessment of the channel can be made and results using topside update may be compared.

In the process of doing the experimental design it was decided to attempt the update directly from the oblique sounder network as an additional technique. In order to test this idea, at least two simultaneous sounder links had to be operating such that one path could be used as a source for the update and the second path, an arbitrary unknown path in practical applications, could be the path against which the updated model calculation was compared. After several opportunities to collect appropriate data were cancelled, NRL finally participated in the NATO Teamwork '80 exercise in September of 1980. Since topside sounder coverage was unavailable directly overhead in the area of Teamwork '80, the primary objective of this exercise was to obtain the type of oblique sounder data against which the model update could be performed using the oblique sounder data directly. The model update using oblique sounder data as a source, therefore, is the subject of this memorandum report.

2.2 The Equipment

The data obtained from the TRQ-35 receiver is in the form of Polaroid photographs of the oblique sounding ionogram. For short paths, the sounder network is set up to operate between 2 and 15 MHz, and for long paths the limits are 2-30 MHz. A sounding requires four minutes and forty seconds to complete. The equipment has the capability to record as many as three different stations, with each transmitting in a different five minute time slice of a fifteen minute period. Figure 1 shows the sounder receiver display and the important parameters which are extracted from that data (7). Three different parameters are scaled from these data. The first is the cutoff point for ionospheric propagation between the transmitter and receiver known as the maximum usable frequency (MUF). In the example shown here, the maximum usable frequency is 7.6 MHz. The second parameter scaled is the band of frequencies in which optimum transmission might occur. This is called the FOT band. The FOT band is defined as that region in the data where that the signal strength is high and no multi-path is evident. In the example shown here, the FOT band occurs between approximately 3.7 MHz and 6.1 MHz with the best frequencies being near 6.1 MHz where absorption should be the lowest. The last parameter scaled is the lowest usable frequency or LUF. The LUF is the frequency where the low cutoff occurs and is typically determined by D-region absorption. In this case the lowest usable frequency appears to be slightly above 2 MHz.

The data shown in Figure 1 also contains a histogram at the top of the display indicating the signal strength at each of the received frequencies. The histrogram actually is a plot of the receiver AGC. Since this oblique sounding equipment is user oriented and not research instrumentation, the full amount of information normally available by properly thresholding the receiver such that the noise floor is slightly evident, is not available here. However, for the communications problem being addressed with the instrument, it is only important to ascertain the

MUF, FOT, and LUF. Hence, excepting the fact that the manpower overhead is high to record a complete set of data, the equipment is quite usable and the data is easy to scale.

## 3.0 DISCUSSION

The essence of the model update technique is illustrated by Figure 2. A model calculation of the diurnal variation of the maximum usable frequency for a circuit is performed using the appropriate parameters which drive the model. This step is illustrated by the line labeled "model application". The actual data is plotted against this computation and in most cases the model has a bias with trends tending to be agreeable. The next step is to extract a reading of the appropriate parameter (MUF for this case) at one point in time from the oblique sounder. The model is then forced to fit this point by varying the relavant driving parameters. This step is indicated by the center plot of the figure labeled "known path". The model that is currently being examined, MINIMUF 3.5, is fitted by varying the driving parameter which is sunspot number. This sunspot number derived from the force fit is then used to generate like computations over other paths and these are compared directly with sounder data to determine how well the technique worked. This is illustrated in the figure by the plot labeled "unknown path".

One objective of this work is to ascertain the spatial and temporal perishability of a model update. This can be satisfied by testing the performance of various models over a large enough data base. The current model being tested is MINIMUF 3.5, but others are envisioned for testing in this manner such as IONCAP and HFMUFES. It is expected that the model update scheme will work well over a local area. If this can be verified, a single oblique sounder path in the mid-latitude Atlantic, for example, could be used to update the appropriate model and this updated model could be used to obtain accurate forecasts of the maximum usable frequencies of other links operating in that area. Experimentally, of course, this is determined by actually having sounder measurements over paths other than the reference path. Experimental results will be shown in the following sections which indicate the initial success of this technique.

## 4.0 RESULTS

### 4.1 Mt. Whitney Operations; September 18-19, 1980

In the past, obtaining the type of data required to validate this technique has been difficult. Data is required from two or more oblique sounder paths operating simultaneously in a local area. One path is used to update the model and other paths can be used to check the success of the update. NRL's first opportunity to obtain data of this kind occurred in September, 1980. An NRL representative went on board the USS Mt. Whitney to obtain oblique sounder data from a net which was being used to support the NATO Teamwork '80 exercises. Figure 3 is a map of the experimental setup in the September 18-19 time frame. A sounder transmitter was located at Soc Buchan, Scotland, labeled $T_1$; Kolsaas, Norway, labeled $T_2$; and Orland, Norway, labeled $T_3$. The USS Mt. Whitney, on-board which the

receiver was located, was anchored off the coast of Norway. This is denoted by R. Path lengths are 830 km ($T_1$-R), 340 km ($T_2$-R), and 104 km ($T_3$-R). Since NRL could have only one representative on-board to gather data and the data had to be obtained in the form of Polaroid photos, it was extremely difficult to get a continuous set of data for the full exercise period. However, on the 18th and 19th of September, the technician worked a straight 24-hour period in order to obtain one complete day of data. Partial days are also in the data base for the period 9 September - 23 September. The existence of one complete diurnal cycle was the determining factor in the selection of the sample of data on which the update technique was first tested.

4.2 The Un-updated Model

To determine the improvement gained by employing this technique, the model was run in its standard recommended mode (4) whereby the five day running average of 10.7 centimeter flux was used to drive the model. This model calculation was compared with the actual maximum usable frequency as scaled from the data and the RMS error was computed. Figure 4 shows this comparison. The vertical lines indicate the difference between the model and the actual maximum usable frequency as measured every 15 minutes by the sounder over the Soc Buchan to Mt. Whitney path ($T_1$-R). Note that the difference between the model and the actual data has an RMS error of 3.82 MHz. This is in good agreement with the advertised accuracy of MINIMUF 3.5 (4). Figure 5 is the same type of calculation, but for Kolsaas, Norway to the Mt. Whitney. The calculated RMS error here is 4.03 MHz.

4.3 The Updated Model

Next, the update was attempted using the Kolsaas path as the source path. The model was forced to fit the measured MUF on that path at 0600Z. From the forced fit, a sunspot number was extracted and used to drive the model for the Soc Buchan to Mt. Whitney path. The results from these updates are shown in the next two figures. Figure 6 indicates the model update calculation for the Soc Buchan path whereby the Kolsaas path was used to derive the applicable sunspot number. In this case, note the marked improvement in the model fit to the data. The RMS error has dropped to 1.64 MHz with the largest portion of that error occurring in the evening when scattering phenomena led to increased scaled maximum usable frequencies.

Figure 7 indicates the improvement in the Kolsaas path model calculation. Here the RMS error is 2.87 MHz and again, most of that error is due to the scatter propagation which occurred.

Since the MINIMUF model has no capability to predict scatter, the data was rescaled to remove the scatter. Figure 8, which is an example of the actual data, indicates how this could be done. First note the "extended nose" of the ionogram which is attributed to scattering phenomena. Working back in the ionogram, one can see the standard portion of the ionogram where o-x splitting occurs. Hence, it was relatively simple to identify the point where the standard MUF exists.

The next two figures show the result of the update with the scatter removed. Figure 9 is the longer Soc Buchan to Mt. Whitney path. The calculated RMS error has dropped to .85 MHz indicating an extremely good fit to the actual data. Figure 10 is the comparison of the Kolsaas to Mt. Whitney path. It also shows a .85 MHz RMS error, again indicating a good fit.

An additional subtlety should be noted in this analysis. There was an approximate two hour shift to the left of the MINIMUF model calculation relative to the actual data. This was removed. At this point no attempt is made to explain this shift. However, the problem is simply handled by matching the model sunrise with the data sunrise and then performing the fit from that point. It has been indicated that September-October MINIMUF model calculations at high latitudes over short paths have shown this shift in the past and at present this is not understood. It is suspected, however, that at high latitudes near equinox, there is a seasonal effect which is responsible for this result (2).

Table I below is a summary of the data examined so far indicating the improvement in the forecast using the model update for the September 18-19 time frame with the scatter removed. A number of different computations were attempted. Situation #1 is the case where the MINIMUF model was driven using the actual five day running average of 10.7 centimeter flux. The RMS error for each path is calculated. It was noticed during the analysis that the 10.7 centimeter flux and the sunspot number which NRL had access to did not convert by the algorithm in MINIMUF. Hence, situation #2 was generated using the five day running average of sunspot number. The third case used the one day sunspot number since February 18 was more active than the previous four days. The RMS error declined further. As mentioned earlier, the MINIMUF calculation was shifted relative to the actual data. Hence, MINIMUF was shifted to remove this error and situation #4 reflects that calculation with the same driving perameters as situation #1. There is only about a .4 MHz RMS error difference due to the shift. Likewise, situation #5 is comparable to situation #2 and situation #6 is comparable to situation #3. Finally, situations 7-14 indicate the results using a reference path to perform the update. For example, situation #7 utilizes a shifted MINIMUF, where the model was forced to fit on the Soc Buchan path at 0600Z. The resulting sunspot number was then used to derive the Soc Buchan path, and the Kolsaas path. RMS errors are indicated. Several different update times are investigated where situations 8-10 are updates using the Soc Buchan path at 0800Z, 1000Z, and 1200Z respectively.

In order to obtain an indication of the dependence of the technique on path differences, the same update scenario was applied using Kolsaas as the reference path. Situations 11-14 show the RMS errors using that path as the reference with fits derived at 0600Z, 0800Z, 1000Z, and 1200Z, respectively.

TABLE I

IMPROVEMENT IN FORECAST USING UPDATE

Accuracy (RMS Error, MHz) of Update Technique
For Sept 18-19, 1980 Data With "Nose Extension" Removed

| No. | SITUATION | FIT TO RAW DATA SOC BUCHAN | FIT TO RAW DATA KOLSAAS | SSN USED |
|---|---|---|---|---|
| 1 | Actual MINIMUF Using 5 day 10.7 cm Flux | 3.36 | 2.76 | 112 |
| 2 | Actual MINIMUF Using 5 day SSN | 2.65 | 2.22 | 149 |
| 3 | Actual MINIMUF Using 1 day SSN | 1.98 | 1.72 | 197 |
| 4 | Shifted MINIMUF Using 5 day 10.7 cm Flux | 2.97 | 2.43 | 112 |
| 5 | Shifted MINIMUF Using 5 day SSN | 2.07 | 1.75 | 149 |
| 6 | Shifted MINIMUF Using 1 day SSN | .99 | .95 | 197 |
| 7 | Shifted, 0600Z Fit at Soc Buchan | .66 | .63 | 227 |
| 8 | Shifted, 0800Z Fit at Soc Buchan | .75 | .67 | 249 |
| 9 | Shifted, 1000Z Fit at Soc Buchan | .75 | .67 | 249 |
| 10 | Shifted, 1200Z Fit at Soc Buchan | .75 | .67 | 249 |
| 11 | Shifted, 0600Z Fit at Kolsaas | .85 | .85 | 205 |
| 12 | Shifted, 0800Z Fit at Kolsaas | .64 | .62 | 240 |
| 13 | Shifted, 1000Z Fit at Kolsaas | .66 | .63 | 227 |
| 14 | Shifted, 1200Z Fit at Kolsaas | .66 | .63 | 227 |

To further validate this technique another operation of opportunity in the Atlantic was drawn upon in late February, 1981. The path lengths were 1000-2000 km and these were at mid-latitude. Preliminary results indicate that the update technique worked almost as well as the example shown herein with RMS error dropping to near 1 MHz for a 24 hour period. Those results will be reported in a future document.

## 5.0 SUMMARY

In the near future the U. S. Navy will be deploying a number of oblique ionospheric sounders to be used to improve HF long haul communications. In addition, a great deal of work is being done with the PROPHET prediction system to determine effective use of propagation tactics as well as asset management based on the condition of the propagation environment. It is NRL's intent to examine the coupling of these two instruments into a system which will provide greatly increased propagation assessment and forecasting accuracies. Initial results indicate this is a reasonable idea and significant improvement may be gained by marrying oblique sounding and PROPHET-type systems. Although this technique has not been validated over a large variety of links under various conditions, initial indications are that this should be done to verify the possibility that large increases in short term forecasting accuracy might be effected.

## 6.0 CONCLUSION

RMS errors near 1 MHz between a model calculation and the actual maximum usable frequency for an HF circuit indicates an extremely useful

technique for making accurate decisions regarding tactics which take into account the effect of the propagation medium. The model update work represented herein should be verified over various geographies at various times of the year. At the same time, other models used by the community such as IONCAP and HFMUFES should also be examined in this context. It is the intent of the performers at NRL to do this as follow-on work. Verification of this technique on a general basis could lead to a major advance in the use of computerized assessment and forecasting to employ propagation tactics and to effect greatly increased efficiencies in the use of frequency assets and channel reliabilties in the future.

## 7.0 ACKNOWLEDGEMENTS

Any technical endeavor requires the input and assistance of numerous people. The work represented here is no exception and several key individuals are acknowledged. First, Navy CAPT Henry Orejuella is gratefully acknowledged for initially supporting this idea and providing funding. Mr. Bill Juchsch at CINCLANTFLT and Mr. Ray Rozanski have also been key supporters. The data could not have been taken if it were not for the tireless efforts of Mr. Tom Priddy who rode the Mt. Whitney in September. Mr. Larry Harnish has been indispensable in scaling the data and writing analysis software. Finally, Mrs. Gailyn Nocente has been extremely patient with the author through numerous revisions written in what amounts to hieroglyphics.

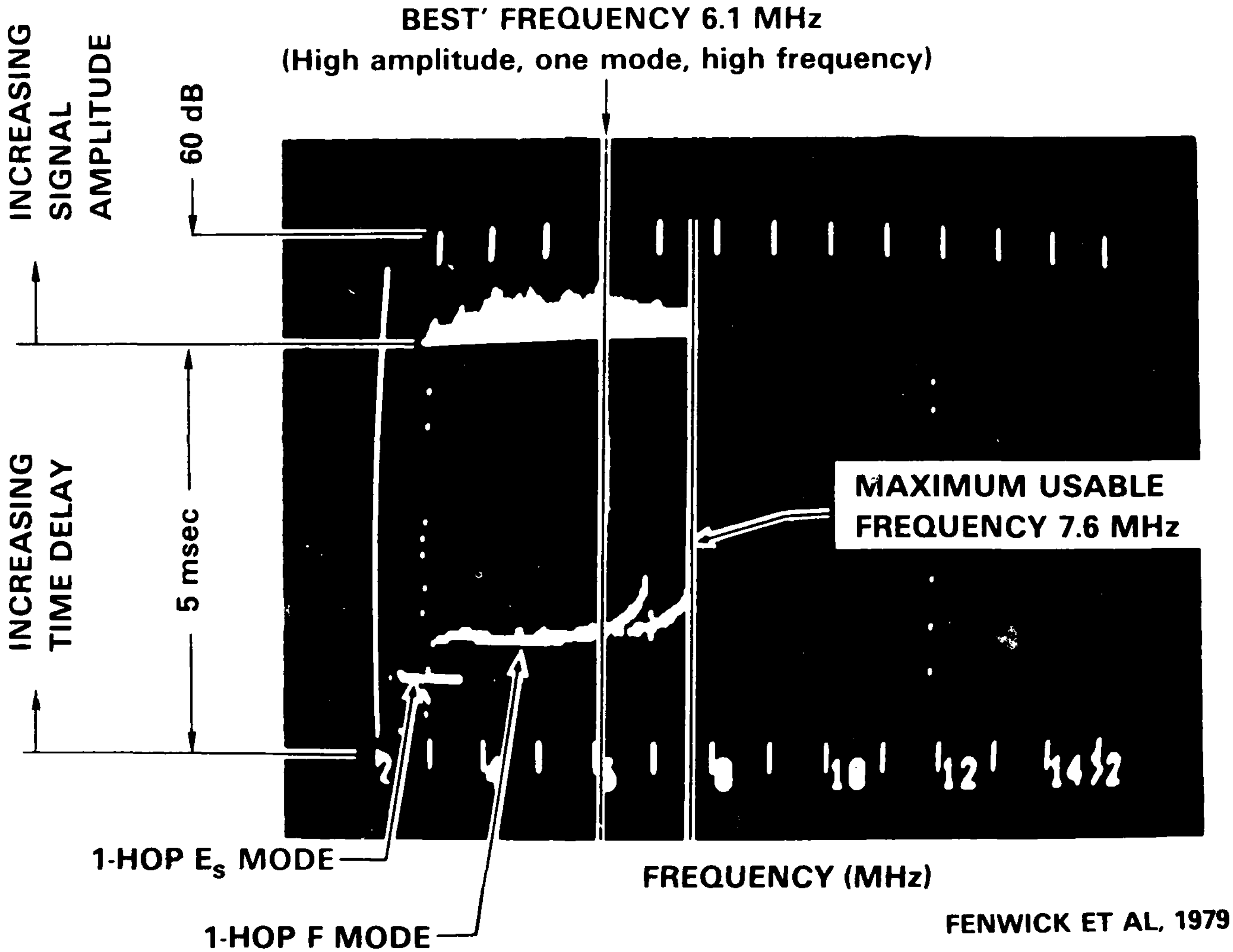



Fig. 1 — Sample display from TRQ-35 sounder receiver with important communications parameters annotated

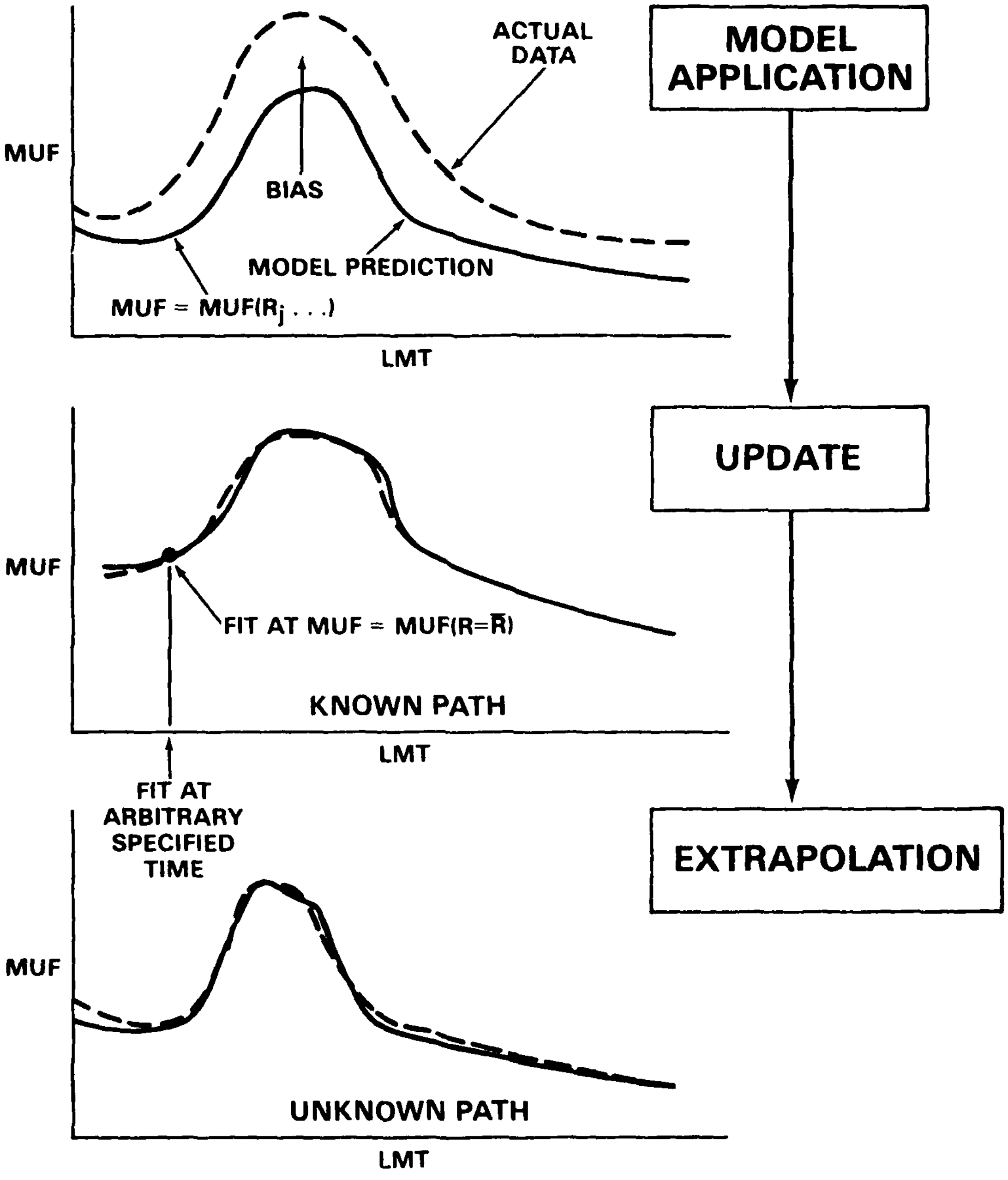



Fig. 2 — Graphical description of the model update approach for the diurnal variation of the Maximum Usable Frequency (MUF) over an arbitrary path

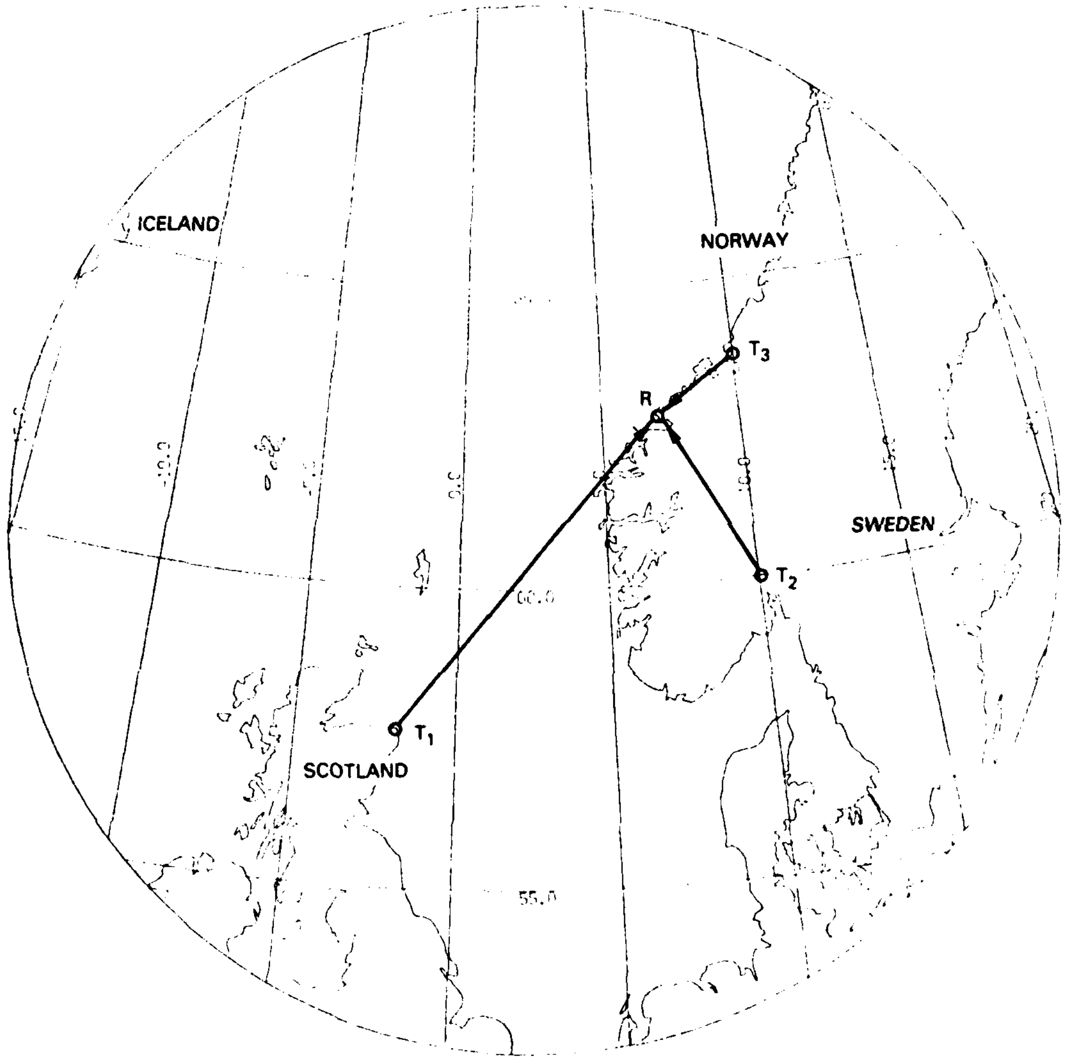
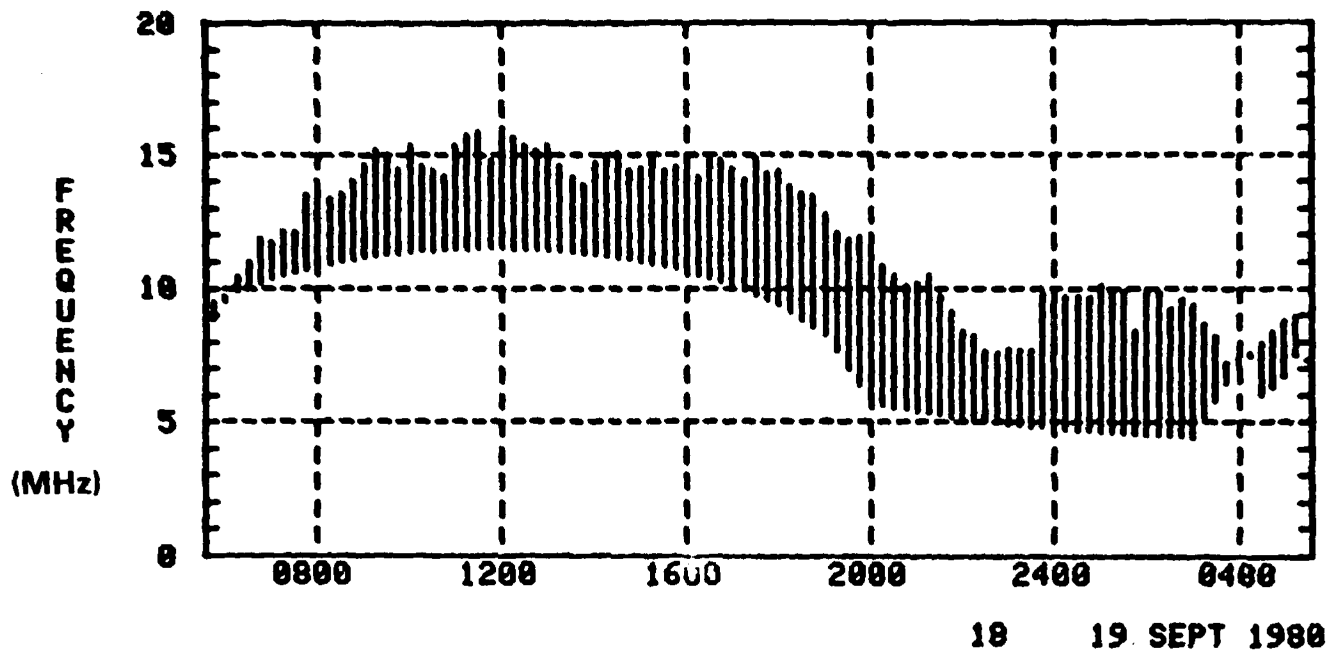



Fig. 3 — Great circle map showing propagation paths for Teamwork '80
on September 18-19, 1980




TRANSMITTER:
SOC BUCHAN SCOT
57.3N, 1.5W

RECEIVER:
USS MOUNT WHITNEY
62.95N,8.34E

SUNSPOT NUMBER = 112
10.7 CM FLUX = 156

R.M.S. ERROR = 3.02MHZ

MINIMUF TIME DELAYED 0 HRS.

Fig. 4 — Difference between the measured MUF and the unupdated modelled MUF over the Soc Buchan, Scotland to ship path on September 18-19, 1980

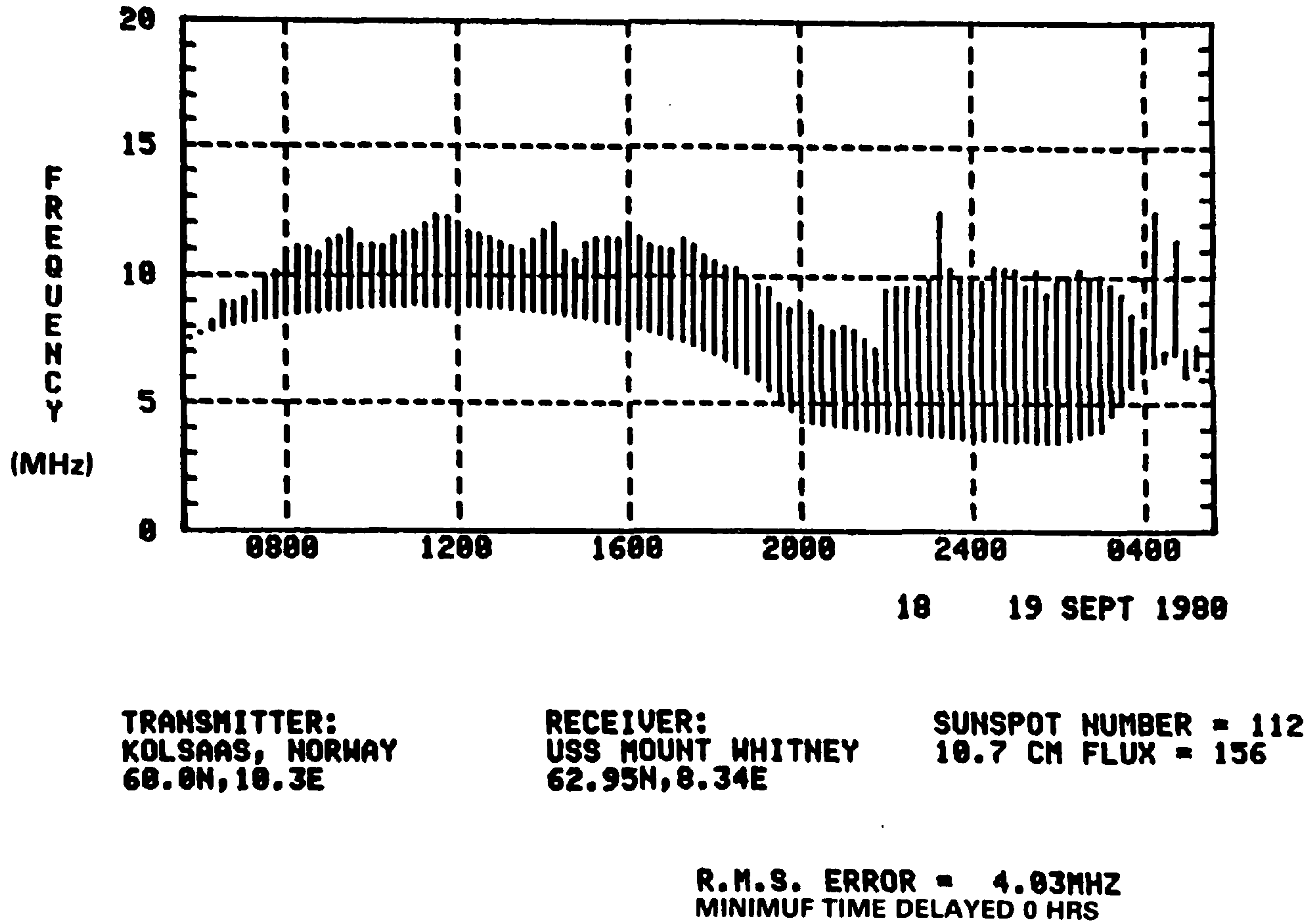
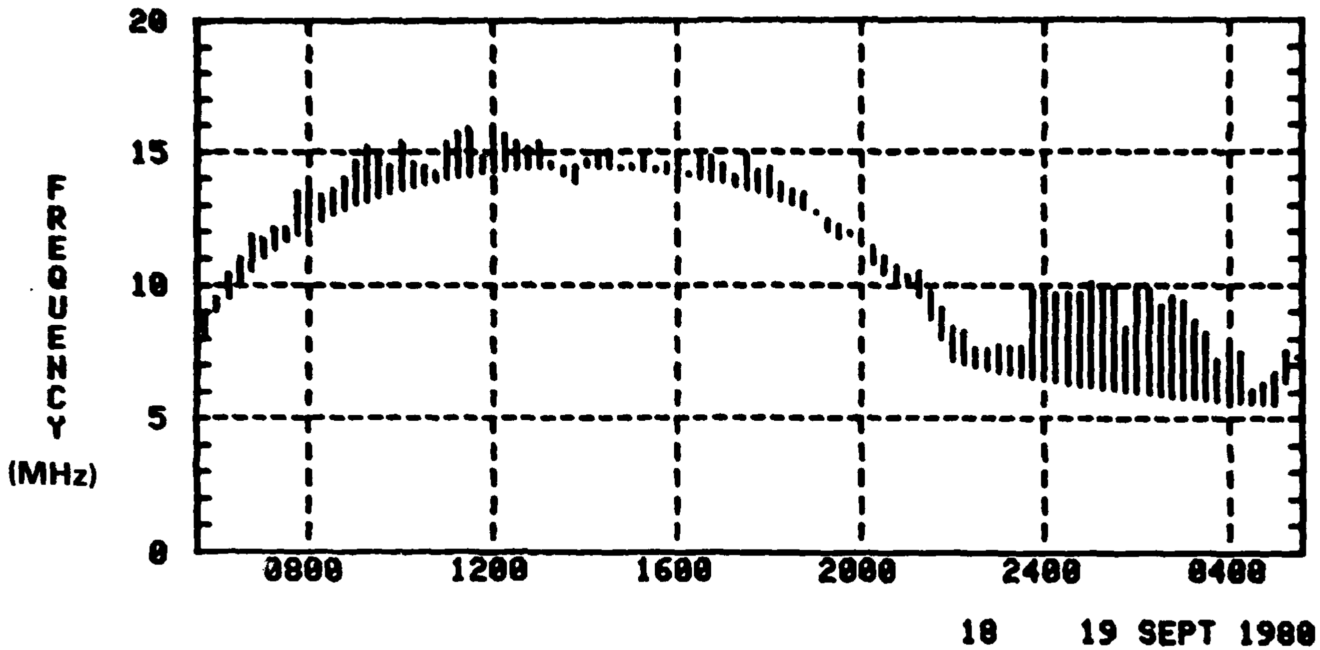



Fig. 5 — Difference between the measured MUF and the unupdated modelled MUF over the Kolsaas, Norway to ship path on September 18-19, 1980




TRANSMITTER:
SOC BUCHAN SCOT
57.3N, 1.5W

RECEIVER:
USS MOUNT WHITNEY
62.95N,8.34E

SUNSPOT NUMBER = 205
10.7 CM FLUX = 250

R.M.S. ERROR = 1.64MHZ

MINIMUF TIME DELAYED 2 HRS.

Fig. 6 — Difference between the measured MUF and the updated modelled MUF over the Soc Buchan/ship path for September 18-19, 1980

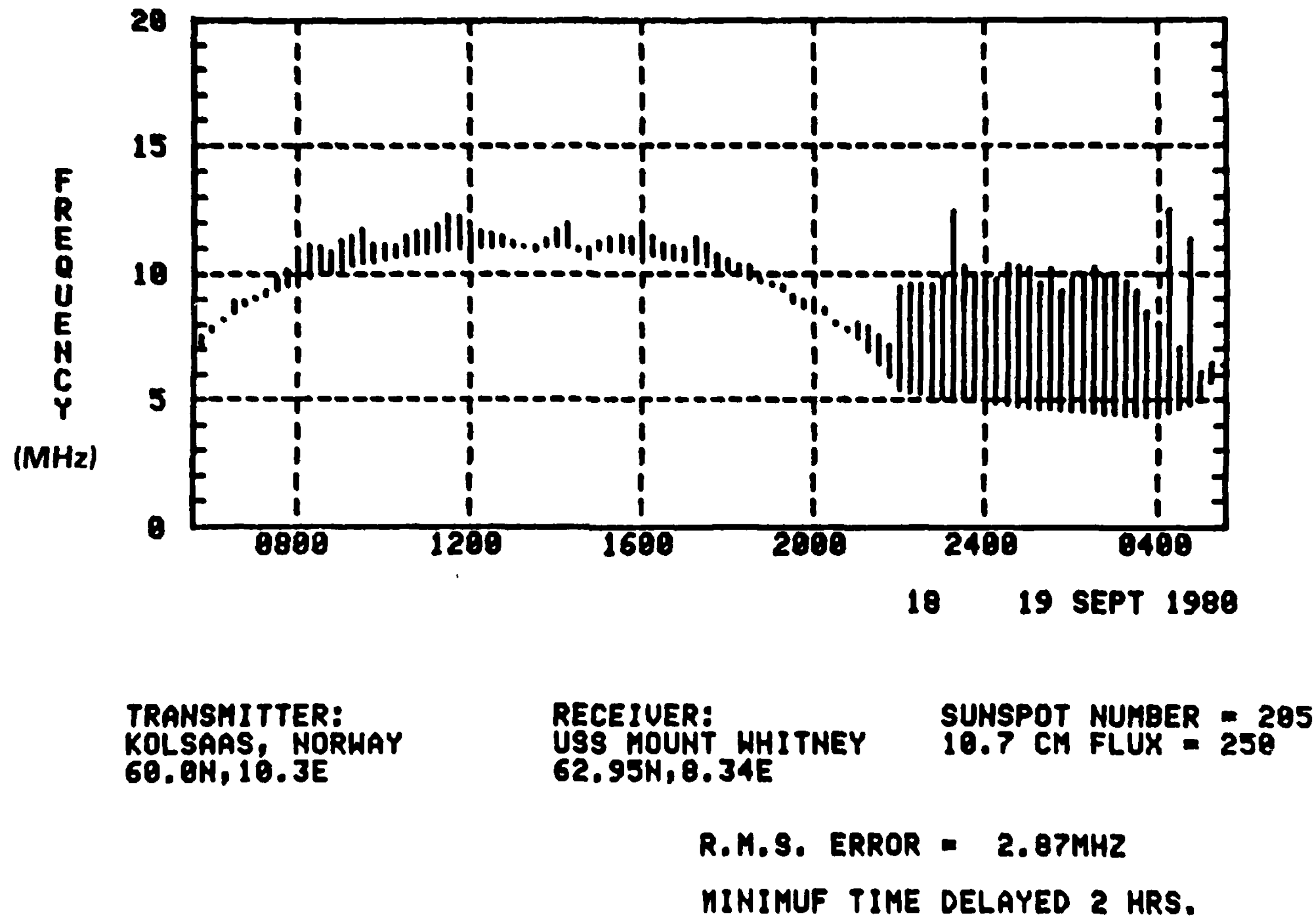



Fig. 7 — Difference between the measured MUF and the updated modelled MUF over the Kolsaas/ship path for September 18-19, 1980

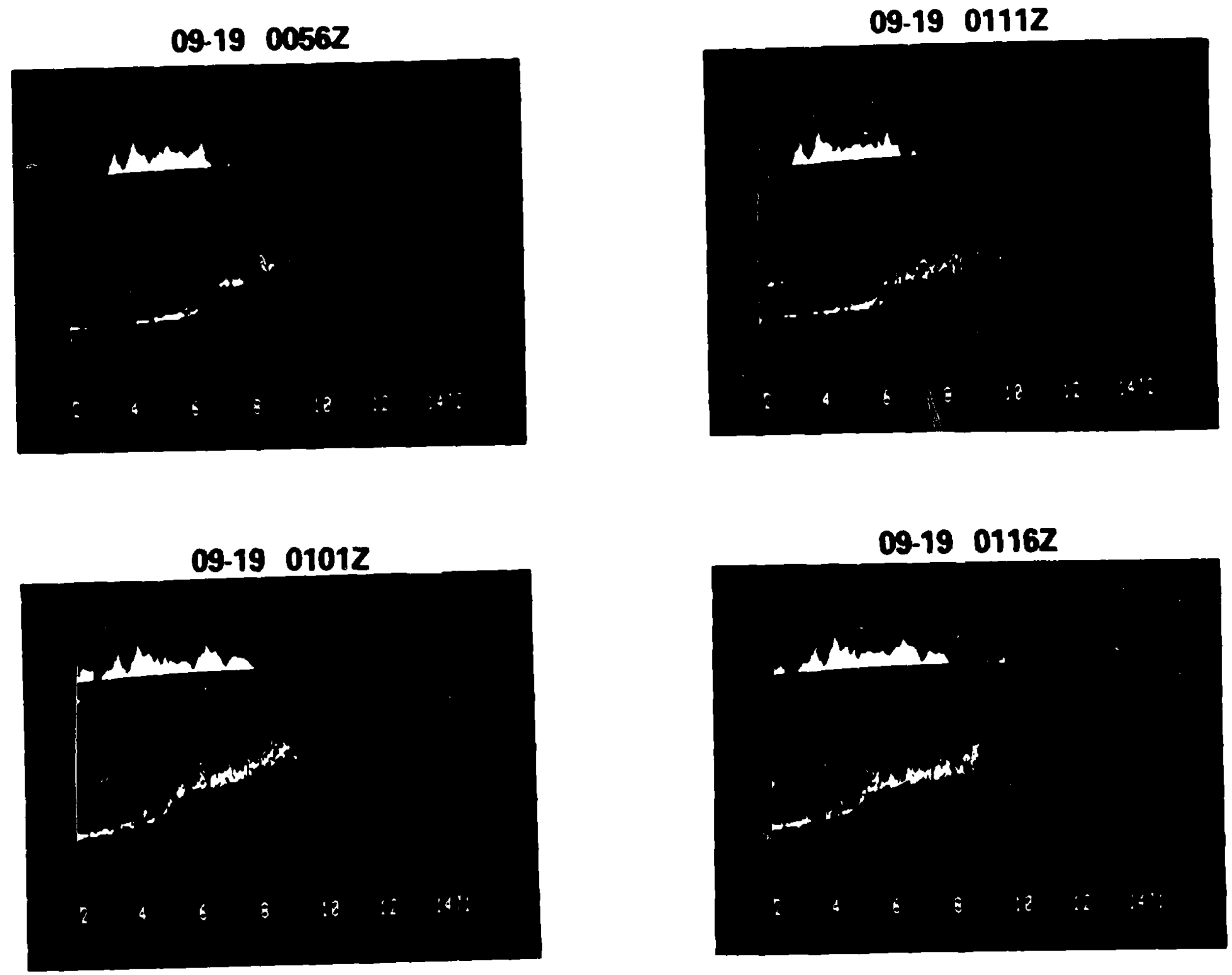



Fig. 8 — Oblique ionograms showing scatter propagation responsible for extended MUF (nose extension)

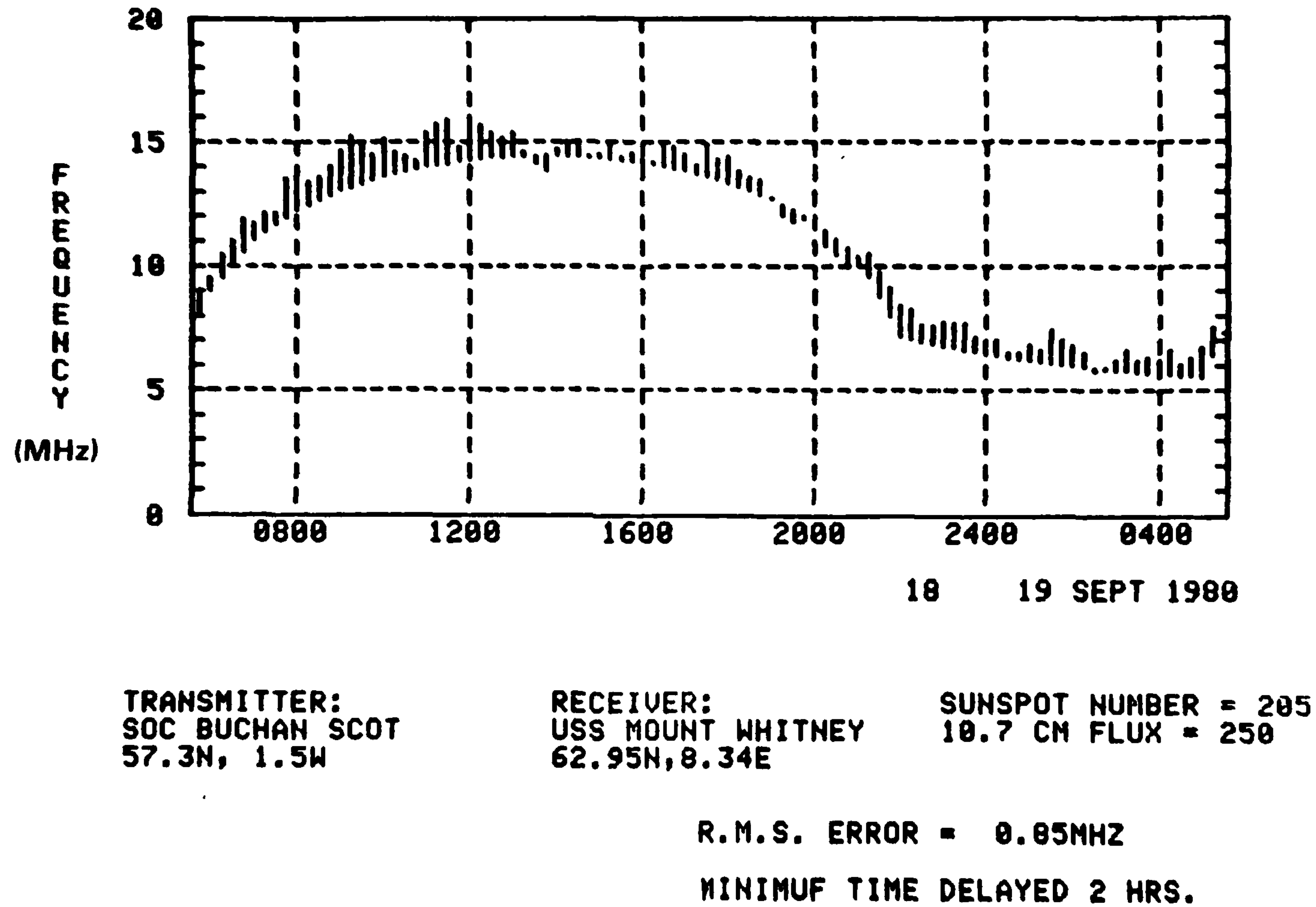
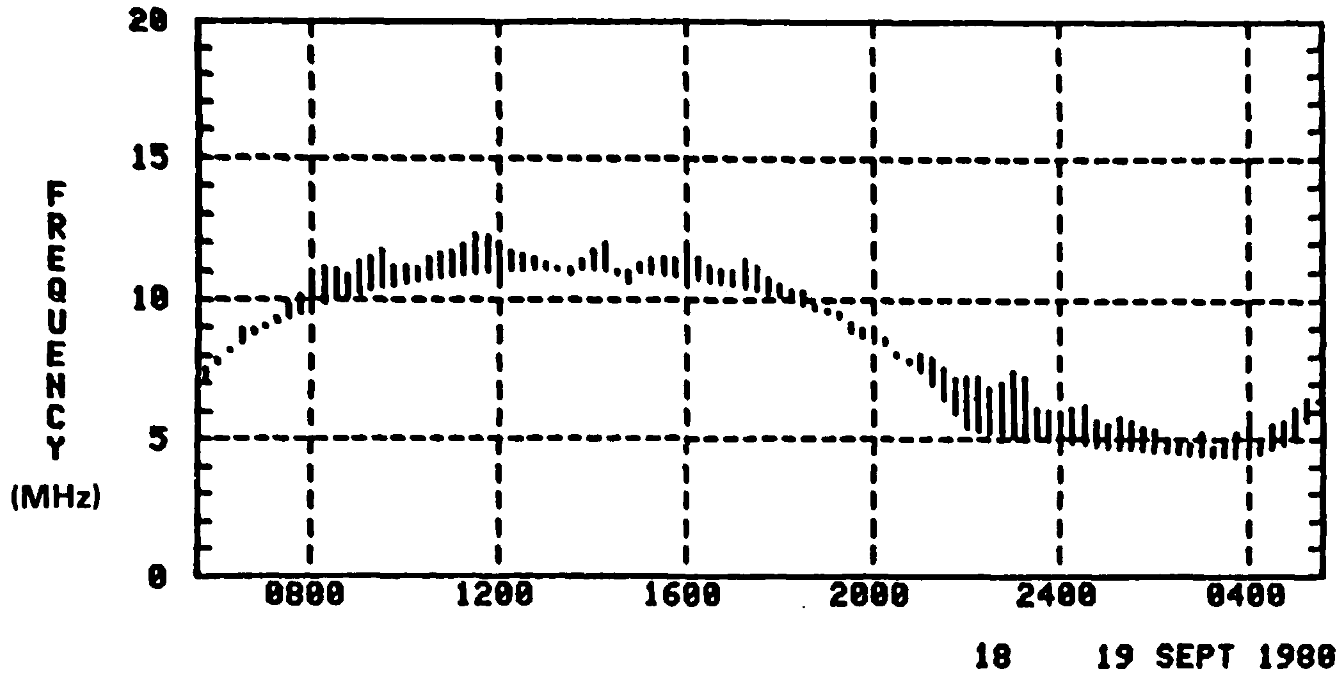



Fig. 9 — Difference between the measured MUF with the "nose extension" removed and the updated model calculation over the Soc Buchan/ship path for September 18-19, 1980




TRANSMITTER:
KOLSAAS, NORWAY
60.0N,10.3E

RECEIVER:
USS MOUNT WHITNEY
62.95N,8.34E

SUNSPOT NUMBER = 205
10.7 CM FLUX = 250

R.M.S. ERROR = 0.85MHZ

MINIMUF TIME DELAYED 2 HRS.

Fig. 10 — Difference between the measured MUF with the "nose extension" removed and the updated model calculation over the Kolsaas/ship path for September 18-19, 1980

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